INVENTORY AND MONITORING OF NATURAL VEGETATION AND RELATED RESOURCES IN AN ARID ENVIRONMENT

A Comparative Evaluation of ERTS-1 Imagery

Barry J. Schrumpf, James R. Johnson, and David A. Mouat
Rangeland Resources Program
Oregon State University
Corvallis, Oregon 97331

March 20, 1973
Type II Progress Report for Period September 1, 1972 - February 28, 1973

Prepared for
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
INVENTORY AND MONITORING OF NATURAL VEGETATION AND RELATED RESOURCES IN AN ARID ENVIRONMENT - A Comparative Evaluation of ERTS-1 Imagery	March 20, 1973
	6. Performing Organization Code
7. Author(s) Barry J. Schrumpf, James R. Johnson, and David A. Mouat	8. Performing Organization Report No. N/A
9. Performing Organization Name and Address Rangeland Resources Program Oregon State University Corvallis, Oregon 97331	10. Work Unit No.
	11. Contract or Grant No. NAS5-21831
	13. Type of Report and Period Covered Type II Progress Report; September 1, 1972-February 28, 1973
12. Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771 Technical Monitor: Edward W. Crump	14. Sponsoring Agency Code

15. Supplementary Notes

N/A

16. Abstract

A vegetation classification has been established for the test site (approx. 8300 sq. km); 31 types are recognized. Some relationships existing among vegetation types and associated terrain features have been characterized. Terrain features can be used to discriminate vegetation types. Macrorelief interpretations on ERTS-1 imagery can be performed with greater accuracy when using high sun angle stereoscopic viewing rather than low sun angle monoscopic viewing. Some plant phenological changes are being recorded by the MSS system.

17. Key Words (Selected by Author(s))	18. Distribution Statement
natural vegetation, vegetation inventory, vegetation classification, terrain feature, geomorphology	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
N/A	N/A		

Preface

This study has been designed to provide the basis for evaluating several alternatives for incorporating ERTS-1 data into vegetation inventory procedures. Additionally, some comparative evaluations with other forms of satellite imagery and multidate high altitude aircraft imagery are included.

A test site in southeastern Arizona has been chosen which includes vegetation types representative of Sonoran and Chihuahuan Desert shrub, grassland, chaparral, mixed needleleaf and broadleaf woods, and needleleaf forests. The work includes characterizing the level of interpretive detail in repetitive ERTS imagery, characterizing vegetation-physical terrain feature relationships, comparing macrorelief interpretations using low sun angle monoscopic versus high sun angle stereoscopic techniques, detecting plant phenological changes recorded in multidate ERTS data, utilizing ERTS and other satellite imagery in multistage sampling schemes, and determining spectral signatures for some vegetation types from ERTS-1 MSS data.

A vegetation classification including 31 types has been established. A stepwise discriminant analysis has provided a ranking of physical terrain features in order of their value for discriminating vegetation types. Elevation and macrorelief class were ranked highest. Results from an interpretation comparison test indicate that macrorelief can be more accurately identified by stereoscopic viewing of ERTS imagery acquired at a time of high sun angle than by monoscopic viewing of low sun angle imagery.

Interpretation testing of macrorelief and other terrain features on moderate and low sun angle imagery and with stereoscopic viewing is recommended.

TABLE OF CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION

This report conveys work and progress for the first six months of investigations utilizing ERTS-1 imagery acquired over southern Arizona for inventorying and monitoring natural vegetation and related resources. Ground data pertaining to vegetation and terrain features have been collected prior to and during this current research effort. Those data have been used to establish a classification of the vegetation found in a 3200 square mile (approx. 8300 sq. km) test site. Additionally, those data have been used to characterize relationships existing among vegetation types and associated terrain features. Terrain features have been evaluated in terms of their usefulness for discriminating vegetation types. One terrain feature, macrorelief, has been the subject of an ERTS imagery interpretation test designed to accomplish a comparison of (1) imagery acquired under high sun angle irradiation and viewed stereoscopically, and (2) imagery acquired on a date of low sun angle and viewed monoscopically. Color reconstitutions have been produced for six dates of ERTS imagery over the test site using MSS bands 4, 5, and 7; these have received a cursory, qualitative inspection for color changes related to plant phenological changes. NASA high altitude aircraft photography has provided "ground truth" necessary for identifying the plant species or groups of species undergoing phenological changes noted on the satellite multidate imagery.

VEGETATION CLASSIFICATION

The test site selected for this investigation was chosen for its wide variety of natural vegetation. Sonoran and Chihuahuan Desert shrub, grassland, chaparral, mixed needleleaf and broadleaf woods, and needleleaf forest vegetation classes are represented. The inventory and analysis procedures to be developed in this study require that a uniform legend scheme be used for all evaluations. This necessitated development of a vegetation classification. Plant species data acquired for approximately 500 locations in the test site over the past four years were analyzed. Each field location write up contained species presence and prominence data (Poulton, Johnson, and Mouat, 1970). Definitions for prominence ratings are given in Appendix A. Sample locations were chosen to represent photographic image classes recognized on Gemini IV, Apollo 6, and NASA high altitude aircraft photography of the study area. This selection procedure was modified to the extent that rugged terrain and lack of ground access precluded sampling. Access problems were somewhat circumvented through the use of a helicopter (Poulton, et al., 1971). The information procured in this manner was more applicable to vegetation mapping tasks rather than for classification at the level of refinement needed in this study.

A first approximation of a vegetation classification was based on a reconnaissance of the area and a review of literature (Darrow, 1944; Humphrey, 1960, 1963; Interagency Technical Committee (Range), 1963; Lowe, 1964; Nichol, 1952; Pond and Bohning, 1971; Shreve, 1942; Shreve and Wiggins, 1964). On the basis of that review, short lists were compiled of those plant species which seemed to best typify the broad vegetation classes mentioned in the preceding paragraph. The approximate 500 field samples were then sorted into those six broad classes as appropriate according to the match of species listed in each sample with

those in the short list for each class. In this manner, the total number of samples were divided into more manageable groups for analysis, and the sorting brought similar samples together. The samples were further sorted within the six broad classes to produce subgroups when warranted by the similarities and differences among the samples. The criteria for sorting were species presence and species prominence. Woody species tended to receive greater consideration than succulent or herbaceous species; however, there are some notable exceptions to this (*Cereus giganteus, Ferocactus wislizenii, Opuntia* spp., *Nolina microcarpa, Yucca baccata, Y. elata, Sporobolus wrightii,* and *Hilaria mutica*). Vegetation classification work by Garcia-Moya (1972), for a small portion of the test site, provided some useful guidelines for this sorting activity. During this process, several field samples were shifted from one broad class to another. As subgroups became evident, association tables were prepared which provided the means for finalizing decisions about the validity of the subgroups. The resulting classification is based primarily upon the presence or absence of the more common plant species and, secondarily, on the prominence of those species. Each association table showed the species present and their prominence ratings for all field samples belonging to one subgroup. These tables provided the compiled data for the vegetation descriptions which follow. The subgroups established in this manner number thirty-one and are called vegetation types. The name for each type is part of a "technical vegetation legend" for the test site; each description is a part of the "descriptive legend" (Poulton, Johnson, and Mouat, 1970; Poulton, et al, 1970; Poulton, Faulkner, and Martin, 1971).

The vegetation type descriptions conform to a format and consist primarily of elaborated discussions about the plant species. The physiognomy of a group is given first, followed by a discussion of the primary character species. The physiognomic terms are from a technical legend provided in Appendix B. This is followed by a consideration of species within life forms in the following order: trees, shrubs, succulents, and herbs (i.e., grasses). These discussions of species include prominence ratings and a qualitative indication of the regularity (species presence percentage) with which species may be expected to be present among the stands of the vegetation type. The description may be concluded by comments pertaining to the relationship of the type in question to other types.

Larrea tridentata with or without annuals

This vegetation type has a "shrub-scrub" physiognomy, specifically, "microphyllous, non-thorny scrub, generally with succulents."

Larrea tridentata occurs in nearly pure stands, giving a monoculture appearance. However, annuals may be present during periods when sufficient moisture is available. *Zinnia pumila* and *Tridens pulchellus* may be present in low prominence.

This vegetation type appears closely related to the "*Larrea tridentata* with *Prosopis juliflora* and/or *Opuntia* (cholla)" type. The two are often found in close proximity.

Larrea tridentata with *Prosopis juliflora* and/or *Opuntia* (cholla)

The physiognomy of the type is described in general as "shrub-scrub" and in specific as "microphyllous, non-thorny scrub, generally with succulents."

Larrea tridentata almost always maintains high prominence (5) in this type, however, other species of similar stature are present and often conspicuous. *Prosopis juliflora* is one of these. Cacti, especially cholla (mostly *Opuntia fulgida*) are also usually present and occasionally high in prominence.

Other tall shrub species are commonly present but generally in low prominence (1-2). These include *Fouquieria splendens, Acacia constricta, Cercidium floridum* and *C. microphyllum,* among others. The low statured *Zinnia pumila* is nearly ubiquitous and is often joined by *Haplopappus tenuisectus* and/or *Coldenia canescens.*

Stem succulents, as previously mentioned, are a characteristic feature of the type. The chollas (*Opuntia fulgida* and/or *O. spinosior*) are usually present in mid-prominence (2-3). *Ferocactus wislizenii* is also common but in low prominence (1-2).

Grasses are a conspicuous component of most stands. *Tridens pulchellus* is normally present and in substantial prominence (3-4) while *Muhlenbergia porteri* is common and has low to mid-prominence (1-3).

The type appears related to "*Larrea tridentata* with or without annuals."

Atriplex canescens and *Prosopis juliflora*

The physiognomy of this vegetation type is "shrub-scrub," esp. "microphyllous saline tolerant and related scrub types."

Atriplex canescens and *Prosopis juliflora* occur together in restricted areas. The prominence of the two species is quite variable (2-5), but in general one or the other or both tend to rank highest in prominence.

The variety of other shrub species is generally limited but may include *Larrea tridentata, Haplopappus tenuisectus, Zinnia pumila,* cholla (*Opuntia* spp.), and *Fouquieria splendens* among others. Grass prominence generally is not high, but several genera are often represented including *Muhlenbergia, Sporobolus,* and *Andropogon.*

Cercidium microphyllum and *Cereus giganteus* often with *Encelia farinosa* and *Opuntia* spp., and without *Franseria deltoidea*

This vegetation type has a "shrub-scrub" physiognomy, specifically, "microphyllous, non-thorny scrub, generally with succulents."

Cercidium microphyllum is usually prominent or coprominent (4) and is generally accompanied by *Cereus giganteus, Encelia farinosa,* and a variety of cacti. For purposes of type recognition, the absence of *Franseria deltoidea* need also be recognized.

A variety of shrub species may be present in this rather floristically rich type including *Prosopis juliflora, Acacia constricta, Celtis pallida, Zinnia pumila,* and *Larrea tridentata.* Most do not occur in high prominence, but *Larrea* can achieve a high rank (4) in a few stands.

Several cacti species contribute to the type, with at least one occurring in each stand. Prominences rate mid-to-low. From most to least common, the cacti are *Opuntia* spp. (prickly pear, cholla), and *Ferocactus wislizenii.*

An immense variety of forbs and grasses, both annuals and perennials, make a marked seasonal floral impression.

Coldenia canescens, Zinnia pumila, Fouquieria splendens, and *Tridens pulchellus*

The vegetation of the type has a "shrub-scrub" physiognomy.

Coldenia canescens and *Zinnia pumila* clearly are the prominent shrubs in this type giving a low shrub aspect. Other low shrubs that may be present include *Calliandra eriophylla, Ephedra trifurca, Psilostrophe cooperi,* and *Condalia lycioides.* Their prominences tend to be low. Taller shrubs are common, particularly *Fouquieria splendens, Prosopis juliflora,* and *Acacia constricta,* but they are never abundant enough to create a tall shrub aspect.

Succulents are also common including some or all of the various *Opuntia* (chollas and prickly pear) and *Yucca.* Grasses, other than *Tridens pulchellus* and *Muhlenbergia porteri* are noticeably sparse.

Acacia vernicosa, Flourensia cernua, and *Larrea tridentata,* without *Rhus microphylla* and *Dalea formosa*

The physiognomy of this type is "shrub-scrub," specifically "microphyllous thorn scrub."

The three species which characterize the type are the shrubs, *Acacia vernicosa, Flourensia cernua,* and *Larrea tridentata.* All

three are usually present with one of the three being most prominent or at least two of the species sharing prominence. The absence of *Rhus microphylla* and *Dalea formosa* needs to be recognized to prevent confusion with a similar type.

In addition to the shrub species mentioned, several others may be present including, but not limited to, *Zinnia pumila, Parthenium incanum, Fouquieria splendens,* and *Prosopis juliflora.* These species usually have mid-to-low prominence values.

The primary leaf succulent is *Yucca elata* which is present only occasionally. Stem succulents are not common in the type, with *Opuntia phaeacantha* most often present.

Perennial grasses are usually present, and usually in mid-prominence. *Bouteloua eriopoda* and *Muhlenbergia porteri* are usually present, and *Hilaria mutica* occasionally is. The biennial grass, *Tridens pulchellus,* usually is present.

This vegetation type is closely related to the one identified as "*Acacia vernicosa, Flourensia cernua, Larrea tridentata,* and *Rhus microphylla.*"

Acacia vernicosa, Flourensia cernua, Larrea tridentata, and *Rhus microphylla*

"Shrub-scrub" ("microphyllous thorn scrub") is the physiognomy of this vegetation type.

The shrub, *Rhus microphylla,* is always present in the type, usually in mid-prominence. In most stands, two or more of the other three characteristic shrub species (*Acacia vernicosa, Flourensia cernua,* and *Larrea tridentata*) are present, and one of these will occupy the position of highest prominence. Any of several other shrub species may be present, but they usually have mid-to-low prominence (3-1). *Zinnia pumila* and *Parthenium incanum* are very common. Some of these other species which are occasionally present include *Condalia spathulata, Ephedra trifurca, Fouquieria splendens, Koeberlinia spinosa,* and *Krameria parvifolia.*

Leaf succulents may be present, but usually in low prominence. The more common species are *Yucca baccata, Y. elata,* and *Nolina microcarpa.* Stem succulents are rare.

Perennial grasses are common with the genera, *Aristida, Bouteloua,* and *Muhlenbergia* most frequently represented. *Tridens pulchellus* is the most common grass species and it is usually present. Prominence values of individual grass species cover the range (5-1), but most are mid-to-low range (3-1).

The type is related to and resembles "*Acacia vernicosa, Flourensia cernua,* and *Larrea tridentata* without *Rhus microphylla* and *Dalea formosa.*"

Aloysia wrightii usually with *Fouquieria splendens, Acacia constricta,* and *Opuntia* (prickly pear)

This vegetation type has a "shrub-scrub" physiognomy and varies from "microphyllous thorn scrub" to "microphyllous, non-thorny scrub, often with succulents."

The most prominent species generally vary among *Fouquieria splendens, Aloysia wrightii,* and *Acacia constricta* and their combinations, although the latter is frequently absent. Grass prominence, especially *Bouteloua,* can be high (4-3). *Opuntia* (prickly pear), although rarely prominent, (mostly 3), is the remaining species which serves best to characterize the type.

Type variation can be regionally correlated. Toward the southeast portion of the study area *Parthenium incanum, Flourensia cernua, Larrea tridentata, Mimosa dysocarpa, Acacia vernicosa,* and *Dasylirion wheeleri* may be included in the type although they are by no means always present or abundant. *Cercidium floridum,* when present in this type, is confined to the western portion of the area. In addition, *Lycium* and *Celtis pallida,* although only occasionally present, are confined to the west. Shrubs common throughout include *Calliandra eriophylla, Prosopis juliflora,* and *Zinnia pumila.* Common succulents include *Opuntia* (cholla), *Agave palmeri,* and *A. parryi.*

Grasses tend to be more common and prominent eastward, but most are found throughout. Species of *Bouteloua* are the most common. *Aristida* and *Muhlenbergia* are also well represented as is *Tridens pulchellus.*

Mortonia scabrella without *Rhus choriophylla*

Stands of this vegetation type have a "shrub-scrub" physiognomic appearance.

Vegetation of this type is identified by the presence of *Mortonia scabrella.* However, the absence of *Rhus choriophylla* is also required for complete characterization.

In most stands, *Mortonia* is the sole prominent (5), but several other shrub species can also be present, and quite abundant (prominence 5-4). The more common species are *Fouquieria splendens, Parthenium incanum, Zinnia pumila, Larrea tridentata, Acacia vernicosa, Calliandra eriophylla,* and *Rhus microphylla.*

Succulents are also common, especially *Dasylirion wheeleri* and *Nolina microcarpa. Agave* spp., *Opuntia* (prickly pear), and *Yucca* spp. occur in fewer stands.

Grasses are abundant, especially species of *Bouteloua* and *Aristida* and *Tridens pulchellus*. Although grass prominence can be high, stands normally maintain a shrub aspect.

This type is well defined and occurs in close proximity to a related and similar appearing type, "*Mortonia scabrella* with *Rhus choriophylla*."

Mortonia scabrella with *Rhus choriophylla*

Representatives of this type usually have a "shrub-scrub" aspect.

Mortonia scabrella and *Rhus choriophylla* when found in combination are the only species that need be recognized to identify this vegetation type. In most stands, *Mortonia* is the sole prominent (5), yielding a shrub aspect. Other shrubs are normally not abundant, but may include *Cercocarpus breviflorus*, *Fouquieria splendens*, and *Aloysia wrightii*. A shrubby *Quercus* and *Pinus cembroides* may also be present.

Leaf succulents are common to most stands and most frequently exhibit mid-prominence. The more common species are *Nolina microcarpa*, *Dasylirion wheeleri*, and *Yucca*.

Grasses are most commonly represented by *Aristida* and *Bouteloua*. In some stands grass prominence ranks high enough to give a shrub-grass aspect.

This vegetation type is well defined, occurs in limited habitats, and is found adjacent to and is closely related to the other *Mortonia* type, "*Mortonia scabrella* without *Rhus choriophylla*."

Prosopis juliflora and *Haplopappus tenuisectus* with *Opuntia* (cholla) and without *Acacia constricta* and *Calliandra eriophylla*

This vegetation type is classified as "shrub-scrub" and "microphyllous, non-thorny scrub, generally with succulents."

Prosopis juliflora and *Haplopappus tenuisectus* are the usual prominent (4-5) species of the type, with *Prosopis* the more common sole prominent (5) when the two are not coprominent (4). The consistent occurrence of *Opuntia* (cholla and prickly pear in mid-to-low prominence (3-1)) and frequent occurrence but low prominence (2-1) of *Ferocactus wislizenii* further characterize the type. To distinguish from other types, the absence of *Acacia constricta* and *Calliandra eriophylla* need be noted. For the same reason, the low presence of *Yucca elata* is important.

Several shrub species, in addition to those mentioned above, are found in many of the stands, but none of these species occur frequently or in high prominence. The more common ones are *Acacia greggii, Atriplex canescens, Cercidium floridum, Celtis pallida, Ephedra trifurca,* and *Fouquieria splendens.*

Although grasses are common and fairly prominent (4-2), primarily *Aristida* and *Bouteloua,* they are always decidely subordinate to the shrubs.

This vegetation type is related to "*Prosopis juliflora* and *Haplopappus tenuisectus;* without *Acacia constricta, Opuntia* (cholla), and *Calliandra eriophylla.*"

Prosopis juliflora and *Haplopappus tenuisectus;* without *Acacia constricta, Opuntia* (cholla), and *Calliandra eriophylla*

The physiognomy of the type is "shrub-scrub" specifically "microphyllous, non-thorny scrub, generally with succulents."

In this type, which usually has a tall shrub or low shrub aspect, *Prosopis juliflora* is the most common tall shrub while *Haplopappus tenuisectus* is the most common small shrub. In most stands these species are either prominent (5) or coprominent (4) with grasses (*Bouteloua* and/or *Aristida*). One of the character features of the type is that it has very few shrub species other than those mentioned, and in particular it never has *Acacia constricta* or *Calliandra eriophylla.* Furthermore, cacti are nearly wanting, especially *Opuntia* (cholla) and *Ferocactus wislizenii. Opuntia* (prickly pear), when present, has low prominence values. *Yucca elata* is common with mid-to-low prominence values.

A vast variety of grasses are found in the type and, as indicated, frequently are most prominent. Occasionally, individual species will rank highest in prominence. The most common species are *Bouteloua rothrockii, B. curtipendula, B. eriopoda, Andropogon barbinodis, Muhlenbergia porteri,* and several species represented by the genera, *Aristida, Eragrostis,* and *Setaria.*

A related type is "*Prosopis juliflora* and *Haplopappus tenuisectus* with *Opuntia* (cholla) and without *Acacia constricta* and *Calliandra eriophylla.*

Acacia constricta and *Prosopis juliflora* usually with *Opuntia;* without *Calliandra eriophylla*

The physiognomy of this type is "shrub-scrub."

Acacia constricta is always present in this type which is further characterized by almost always having *Prosopis juliflora.* These two species are generally the most prominent. *Opuntia* (cholla and/or prickly pear) contribute to the type. The absence of *Calliandra eriophylla* needs to be recognized to distinguish this type from some similar types.

A notable feature of the type is its extreme floristic diversity, particularly among shrubs. Some of these are *Acacia greggii, Celtis pallida, Cercidium floridum, C. microphyllum, Ephedra trifurca, Fouquieria splendens,* and *Larrea tridentata.* In most cases these species are present in mid-to-low prominence (3-1).

Grasses, like the shrubs, are present in variety, but generally not in high prominence. The genera *Aristida* and *Bouteloua* are best represented along with the species *Tridens pulchellus* and *Muhlenbergia porteri.*

This vegetation type is similar to "*Acacia constricta* and *Prosopis juliflora* usually with *Opuntia;* without *Calliandra eriophylla.*"

Calliandra eriophylla usually with *Acacia constricta, Fouquieria splendens,* and *Prosopis juliflora* and without *Coldenia canescens*

Stands of this type always have a "shrub-scrub" aspect.

Although this type is characterized by *Calliandra eriophylla,* this species is seldom prominent and, in fact, may occupy a position of low prominence. The aspect of the type is most often one of mixed, tall shrubs. *Acacia constricta, Fouquieria splendens,* and occasionally *Prosopis juliflora* share, or alternately solely occupy, the most prominent position. In some stands, any one of the three species can be absent. Except for the species mentioned above, few other shrub species contribute substantially to the type, although several can be present. The more common of these are *Zinnia pumila, Acacia greggii,* and *Lycium* spp. The near absence of *Haplopappus tenuisectus* and complete absence of *Coldenia canescens* aid in distinguishing this type from others.

Opuntia spp. (primarily prickly pear and some cholla) is the primary succulent. Prickly pear is present in most stands and in mid-prominence. *Ferocactus wislizenii,* although in low prominence, is commonly a component.

Grasses are common, and frequently challenge the shrubs for highest prominence ratings. As is often the case, species from the genera *Aristida* and *Bouteloua* are abundant. Two of the most common species are *Bouteloua curtipendula* and *Hilaria belangeri*.

This type is closely related to "*Acacia constricta* and *Prosopis juliflora* usually with *Opuntia;* without *Calliandra eriophylla*." It is also considered similar to the other two types which have *Calliandra eriophylla* as a character species.

Calliandra eriophylla and *Bouteloua* usually with any or all of *Fouquieria splendens, Acacia greggii, Mimosa biuncifera, M. dysocarpa, Ferocactus wislizenii,* and without *Acacia constricta*

The structural characteristic of the type is primarily an "intergrade" of "scattered tall shrubs over herbs."

This vegetation type tends to be three layered with tall shrubs, low shrubs, and grasses all in high prominence. *Calliandra eriophylla* is always present in the type in widely fluctuating prominence (5-1). The most conspicuous shrub is normally *Prosopis juliflora* which is usually present in mid-to-high prominence. *Acacia greggii, Fouquieria splendens, Haplopappus tenuisectus, Mimosa biuncifera,* and *M. dysocarpa* are present in a number of stands in mid-to-low prominence. The presence of any or all of these five species in conjunction with the other character species suggests the type. *Acacia constricta* is not a component. Relatively few other shrub species are found in the type.

Some succulents are represented in rather low prominence in the type. One, *Ferocactus wislizenii,* is fairly common and is useful in distinguishing this type from a similar one which also contains *Calliandra*.

Of the grasses, *Bouteloua* is best represented often with high prominence (5-4). *B. curtipendula* is the most common grass species. The genera, *Aristida* and *Andropogon,* are also well represented.

The other vegetation types containing *Calliandra* would be considered similar to this type, especially "*Calliandra eriophylla* and *Bouteloua* with any or all of *Ephedra trifurca, Yucca baccata, Y. elata, Prosopis juliflora,* and without *Acacia constricta*.

Calliandra eriophylla and *Bouteloua* with any or all of *Ephedra trifurca, Yucca baccata, Y. elata, Prosopis juliflora,* and without *Acacia constricta*

The physiognomy of the type fluctuates between "herbaceous" types and "intergrades" of "scattered tall shrubs over herbs."

As in some other types, *Calliandra eriophylla* and *Bouteloua* are present and substantially contribute to the herbaceous aspect of the type, even though *Calliandra* is not herbaceous. *Prosopis juliflora* is the most common tall shrub species, and when present it too influences the aspect of the type. *Haplopappus tenuisectus* and *Ephedra trifurca* are important in type identification. Noting the absence of *Acacia constricta*, and near absence of *Acacia greggii*, *Fouquieria splendens*, *Mimosa biuncifera*, and *M. dysocarpa* is important for the same reason. The latter group, when present, are in low prominence.

Y. elata and *Y. baccata* are important succulents. The near absence of *Ferocactus wislizenii* is also characteristic. Several other stem and leaf succulents occur in the type.

Grasses abound and usually have high prominence (5). The genus, *Bouteloua*, has many species represented including *B. curtipendula*, *B. eriopoda*, and *B. rothrockii*. *Aristida* and *Andropogon* rank next to *Bouteloua* in frequency of occurrence and prominence followed closely by *Muhlenbergia* and *Panicum*.

In addition to being related to other herbaceous types, this vegetation type is similar to the others with *Calliandra*, especially, "*Calliandra eriophylla* usually with any or all of *Fouquieria splendens*, *Mimosa biuncifera*, *M. dysocarpa*, *Ferocactus wislizenii*, and without *Acacia constricta*."

Bouteloua and *Aristida* without large shrubs, *Nolina microcarpa*, *Yucca* and *Calliandra eriophylla*

This "herbaceous" vegetation type fits into the class of "sodgrass and mixed sodgrass-bunchgrass steppe and prairie."

Perennials of *Bouteloua* and *Aristida* combine to give this type its herbaceous (grassland) aspect. However, presence of the grasses alone is not sufficient to separate the type from others. In addition to the general observation that there are nearly no large shrubs or succulents, it is meaningful to specifically notice that there is an absence or near absence of *Prosopis juliflora*, *Calliandra eriophylla*, *Haplopappus tenuisectus*, *Nolina microcarpa*, and *Zinnia pumila* in addition to species of the genera *Acacia*, *Agave*, and *Yucca*. Small shrubs are often present in high prominence, but because of their low stature they do not interrupt the grass aspect of the type. *Mimosa biuncifera* and *M. dysocarpa* are the small shrub species most often present.

As a group, perennial *Bouteloua* usually is the sole prominent (5). The most common species are *Bouteloua curtipendula*, *B. gracilis*, *B. chondrosioides*, and *B. eriopoda*. Perennial *Aristida* is present in nearly all stands, but highly variable in prominence. Although other

perennial grass species can be occasionally abundant, the only one consistently present is *Andropogon barbinodis*.

Several types are similar to this one with the major distinguishing features being the presence or absence of associated shrubs.

Prosopis juliflora and *Bouteloua* without *Nolina microcarpa*, *Quercus*, and *Juniperus*

The physiognomy of the type is best expressed as an "intergrade" between a "shrub-scrub" and "herbaceous" type.

Grasses and *Prosopis juliflora* combine to create the herbaceous or grass-shrub aspect of the type. Thus, *Prosopis* normally is not in high prominence (mostly 3) and other tall shrubs and trees are nearly absent. The succulent, *Nolina microcarpa*, is also absent in the type. Two low shrubs, *Haplopappus tenuisectus* and *Calliandra eriophylla*, are also absent.

Mimosa biuncifera is occasionally present and sometimes in high prominence, but because of its stature, it does not interrupt the aspect. The only succulent which is fairly common is *Yucca elata*. *Opuntia* (prickly pear and cholla) when present is in low prominence (2-1).

Species of *Bouteloua* generally rank highest in prominence in the stands of the type, with *B. eriopoda*, *B. curtipendula*, *B. gracilis*, and *B. hirsuta* being the most prominent and common. *Aristida* is normally present and sometimes ranks highest. Occasionally, stands can have unusually high prominences of *Eragrostis*, *Hilaria belangeri*, and *Andropogon barbinodis*.

There appear to be several types to which this vegetation type is related. They include the grasslands without shrubs as well as other *Prosopis-Bouteloua* types.

Bouteloua, *Aristida*, and *Nolina microcarpa* without *Calliandra eriophylla*

Even though a few tall shrubs may be present in the type, the physiognomy is "herbaceous." The vegetation subclass is "sodgrass and mixed sodgrass-bunchgrass steppe and prairie."

The type is characterized primarily by the presence of *Nolina microcarpa* in either the most prominent position or coprominent with grasses. Thus, although some shrubs can be present, they do not contribute greatly to the aspect because of their rather low abundance. The more common shrub species are *Prosopis juliflora*, *Ephedra trifurca*, *Baccharis pteronioides*, and *Rhus microphylla*. *Calliandra eriophylla* is absent.

Succulents other than *Nolina* which are commonly present include *Yucca baccata, Y. elata,* and *Dasylirion wheeleri.*

Bouteloua curtipendula, B. hirsuta, and *B. eriopoda,* in that order, tend to be the most common and abundant grama grasses. As a group perennial, *Aristida* tends to rank second. Although several other grass species can be present, they are seldom abundant.

This vegetation type is similar to other herbaceous types which have an abundance of *Bouteloua.* The differentiating features are primarily based on associated shrubs, trees, or succulents.

Prosopis juliflora bosque

Prosopis juliflora is the most prominent species along some major drainageways, attaining tree-like proportions of 30 feet near the primary river channels, becoming smaller on the flood plains. However, the stature of *Prosopis* on the floodplains qualifies the type as a "woods." Although associated shrubs and understory vegetation may be present in the bosque, the aspect is completely dominated by *Prosopis.*

Hilaria mutica and *Prosopis juliflora*

The physiognomic characteristic for most stands of the type is an "intergrade" of "scattered tall shrubs over herbs."

Hilaria mutica occurs as the prominent or coprominent species with *Prosopis juliflora* usually in and along drainageways. Although several other species can be present in the type, these two completely control the aspect. Some of the more common shrub species that occur but generally in low prominence are *Acacia constricta, Haplopappus tenuisectus, Ephedra trifurca,* and *Zinnia pumila.* A few succulents can also be present, especially *Yucca* and *Opuntia* (cholla and prickly pear). The most common associated grass genera are *Bouteloua, Aristida, Muhlenbergia,* and *Eragrostis.*

Sporobolus wrightii often with *Prosopis juliflora*

When *Prosopis* is present, the physiognomy of the type is an "intergrade" of "scattered tall shrubs over herbs." When absent, the physiognomy is "herbaceous."

Sporobolus wrightii holds the most prominent or coprominent position in this vegetation type which is confined to drainageways. When coprominent, the other species is *Prosopis juliflora.* Thus, depending on the presence or absence of *Prosopis,* the type has a grassland aspect or shrub-grass aspect. Few other shrubs contribute

consistently to the type, and succulents, when present, are sparse. In addition to *Sporobolus*, *Aristida* and *Bouteloua* are common grass components.

Prosopis juliflora and *Bouteloua* with *Quercus* (usually *Q. oblongifolia*) and/or *Juniperus deppeana*

The vegetation type is represented by a variety of physiognomic forms, primarily undifferentiated intergrades. The most consistent structural characteristic is the presence of a well developed herbaceous layer.

The character species of the type are *Prosopis juliflora*, *Bouteloua*, and *Quercus oblongifolia* or *Juniperus deppeana*. Prominence ratings vary greatly for these species from stand to stand. However, in most stands one is either prominent or at least one shares prominence with other species.

In addition to the *Quercus* mentioned, *Q. emoryi* may be present. *Mimosa biuncifera* and/or *M. dysocarpa* are often present, and the genus represents the only shrub form other than *Prosopis* that is commonly present.

Leaf succulents (*Agave palmeri* and/or *A. parryi*, *Dasylirion wheeleri*, *Nolina microcarpa*, and *Yucca* spp.) are frequently present as are stem succulents of the genus, *Opuntia* (cholla and prickly pear). *Agave schottii* is seldom present.

There are several other vegetation types involving *Prosopis* and *Bouteloua* to which this type appears closely related. The presence of an overstory of *Quercus* and/or *Juniper* is the most distinguishing characteristic. There are, however, less consistent characteristics which support the distinction. These other characteristics consist of the less common associated plant species which are more common in the forest and wood physiognomic type.

Cowania mexicana usually with *Juniperus*

This type usually has the appearance of an "intergrade type" of "scattered tall shrub over herbs" or "evergreen sclerophyll shrub" ("shrub-scrub").

Cowania mexicana is the species which determines the character of this vegetation type. In most cases, *Cowania* ranks high in prominence (5-4).

Trees are common to the type but seldom in high prominence. *Juniperus* spp. (juniper) and several species of *Quercus* are about equally common with both genera occasionally represented in a stand.

In addition to *Cowania*, several shrubs contribute to the type mostly in mid-to-low prominence. The more common being *Cercocarpus breviflorus*, *Mimosa* spp., and *Rhus choriophylla*.

Succulents are a very common component, especially *Agave* spp. (other than *A. schottii*), *Dasylirion wheeleri*, and *Nolina microcarpa*.

The herbaceous layer is generally well developed and usually includes *Andropogon barbinodis*, *Aristida* spp., *Bouteloua curtipendula*, *Hilaria belangeri*, and *Muhlenbergia* spp.

This type is not taxonomically closely related to other types in the area.

Quercus and *Nolina microcarpa*; without *Cercocarpus breviflorus*, *Arctostaphylos pungens*, and *Mimosa biuncifera*

The physiognomy of this vegetation type is usually that of "woods" or occasionally "intergrades."

Oaks are the most conspicuous species of the type and are generally prominent (5-4). *Nolina microcarpa* is the other characteristic species; it has a wide range of prominence values. Shrubs not present in the type include *Cercocarpus breviflorus*, *Arctostaphylos pungens*, and *Mimosa biuncifera*.

The usual oak species is *Quercus emoryi*. Others are not frequent but include *Q. arizonica*, *Q. hypoleucoides*, *Q. oblongifolia*, and *Q. reticulata*. *Juniperus deppeana* is occasionally present but normally in mid-to-low prominence.

Shrubs may be present, but usually in low prominence and number of species.

Other than *Nolina*, *Yucca schottii* is the only other leaf succulent consistently present, although occasional species of *Agave* do occur. Stem succulents are not common.

The herbaceous layer is usually well developed. The most common genera are *Andropogon*, *Aristida*, *Bouteloua*, *Eragrostis*, and *Muhlenbergia*.

Quercus and *Mimosa* without *Arctostaphylos pungens* or *Cercocarpus breviflorus*

Representatives of this type are either "woods" or "intergrades" having "scattered trees over an herbaceous layer." In either case, the herbaceous layer is well developed.

The oak, *Quercus emoryi*, is the most characteristic tree species of the type, being almost always present and in a high prominent (5) or coprominent (4) position. *Mimosa biuncifera* is the usual *Mimosa* present and it has widely varying prominences. To distinguish from other types, the absence of *Arctostaphylos pungens* and *Cercocarpus breviflorus* is noteworthy.

Other tree species which are common include *Quercus arizonica* and *Q. oblongifolia*, although evidence suggests that they are not found together. *Juniperus deppeana* and *J. monosperma* may also be present.

Shrubs, other than *Mimosa* are not an important type component. Leaf succulents, however, are common in most stands. The more common succulents are *Agave* spp. (other than *A. schottii*). *Dasylirion wheeleri*, *Nolina microcarpa*, and *Yucca schottii*.

Quercus and *Arctostaphylos pungens* usually with *Mimosa biuncifera*; without *Pinus cembroides*

This vegetation type is expressed in several physiognomic forms including "intergrades" (both scattered tree and shrub over grass), "shrub-scrub," and "woods."

The most characteristic oak is *Quercus emoryi* (prominence mostly 5-3) and it is almost always present. *Arctostaphylos pungens* is always present most often in mid-prominence. *Mimosa biuncifera* and/or *M. Dysocarpa* are also normally present and contribute to the characterization of the type even though they have low prominence. The absence of *Pinus cembroides* further distinguishes this type.

Juniperus deppeana occurs frequently in mid-prominence in several stands of the type and *J. monosperma* in a few. Two additional oaks are not frequently present, but they can be conspicuous. They are *Quercus oblongifolia* and *Q. arizonica*. Several shrub species can also be present, but none of them are consistent and they seldom exhibit high prominence.

Leaf succulents are usually present in mid-to-low prominence. *Dasylirion wheeleri* and *Nolina microcarpa* are most common. *Agave* species including *A. schottii* are also common. *Yucca schottii* is seldom present.

Perennial grasses are usually present, frequently in high prominence. *Bouteloua curtipendula* and species of *Andropogon*, *Aristida*, and *Muhlenbergia* are the most conspicuous.

Quercus, Arctostaphylos pungens, Pinus cembroides, Juniperus deppeana; without *Mimosa biuncifera*

The physiognomy of the type is generally that of woods, but some stands may have a "shrub-scrub" or "intergrade" aspect of "scattered trees over shrubs."

The trees of the type include *Pinus cembroides* in mid-to-low prominence and *Juniperus deppeana* with mid-prominence. *Quercus emoryi* and *Q. arizonica* are the most common oak species and they usually exhibit mid-to-high prominence. The characteristic shrub of the type is *Arctostaphylos pungens*. It exhibits mid-to-high prominence (3-5). Other shrub species are only occasionally present and usually do not exhibit high prominence. For purposes of type recognition, the absence of *Mimosa biuncifera* need be noted.

Two leaf succulents are common to the type. They are *Nolina microcarpa* with mid-prominence and *Yucca schottii* which usually has low prominence. *Agave* spp. and *Dasylirion wheeleri* are only occasionally present. Stem succulents are uncommon.

Perennial grasses are usually present although the herbaceous layer is seldom strongly expressed.

Cercocarpus breviflorus with *Juniperus deppeana* and/or *Pinus cembroides* and usually with *Quercus*

The physiognomic expression of this type is quite variable. Stands appear as "forest and woods," "shrub-scrub," and "intergrades" of several types.

An overstory is always present although it sometimes consists of widely scattered trees over tall shrubs and may be quite inconspicuous. The more common oaks are *Quercus arizonica, Q. emoryi,* and *Q. reticulata. Juniperus deppeana* is usually present with *Pinus cembroides* and is always present when the pine is absent. The character species, *Cercocarpus breviflorus,* usually has a prominence of 5-3.

Garrya wrightii, Rhus choriophylla, and *R. trilobata* are frequent associated shrub species. Species of *Ceanothus* may also be present.

Leaf succulents are always present; *Nolina microcarpa* and *Yucca schottii* are the most consistent. The presence of *Dasylirion wheeleri* in this type correlates well with that of *Pinus cembroides. Agave* spp. are only occasionally present.

Perennial grasses are always present; *Bouteloua curtipendula* is the most common.

Populus fremontii, Fraxinus velutina, Platanus wrightii, and/or *Chilopsis linearis*

Stands of the type normally have a "forest and woods" physiognomy. The type is riparian. The more common trees are *Populus fremontii, Fraxinus velutina, Platanus wrightii,* and *Chilopsis linearis.* They do not, however, necessarily occur together as the type is broadly defined. Several species of oak (*Quercus arizonica, Q. emoryi, Q. hypoleucoides,* and *Q. reticulata*) and *Juniperus deppeana* may also be found in the type. Shrub and tree forms of *Prosopis juliflora* are also present. This type is unique to riparian situations and is not closely associated with other types described.

Pinus, with or without *P. cembroides,* often with *Pseudotsuga menziesii, Quercus hypoleucoides,* and *Q. gambelii*

Physiognomically, representatives of this type are members of "mixed forests of needleleaf-broadleaf."

Several species of pine may be present in a stand of this broad type, although pines do not have to hold positions of highest prominence. Either *Pinus ponderosa* or *Quercus hypoleucoides* is usually the most prominent species. Other species which may be most prominent or coprominent are *Pinus engelmannii, P. strobiformis, Quercus arizonica, Q. emoryi, and Q. reticulata.* Other pines and common tree species include *Pinus cembroides, P. leiophylla, Pseudotsuga menziesii, Juniperus deppeana,* and *Quercus gambelii.* Scattered shrubs and grasses, especially *Muhlenbergia,* can be common in the understory.

This broadly described type is found in the highest elevations of the study area and on a site to site basis may be related to any of the generally lower elevation vegetation types which commonly contain oak and juniper. Included within this type may be inclusions of vegetation types including the species *Populus tremuloides, Robinia neomexicana, Quercus gambelii,* and mountain meadows.

VEGETATION-TERRAIN FEATURE RELATIONSHIPS

Images of the test site obtained from ERTS-1 seldom contain characteristics that can be interpreted directly in terms of the vegetation types. However, those same images provide a considerable amount of detail pertaining to the physical terrain features. In fact, these features are some of the more salient characteristics of the ERTS images and can be used to facilitate and refine vegetation identifications once vegetation-terrain feature relationships are known. A broad range of elevation, all classes of macrorelief, drainage densities, soil parent materials, aspects, slopes, etc., are present and depicted in the images. Descriptions of macrorelief classes are given in Appendix D. These variables were sampled at 250 locations in the test site; the sample locations were chosen in the following manner. The area was accurately stratified with respect to elevation categories of < 3000', 3000'-3500', 3500'-4000', 4000'-4500', 4500'-5000', and > 5000'. It was also stratified with respect to parent materials - the data being drawn from available geologic maps. The numbers of samples taken were chosen such that they were approximately proportional to their respective parent material-elevation area. If an elevation-parent material area were of such small size that proportional-to-area samples were less than three, the number of samples was raised to at least that figure (Mouat, 1972). Actual sample locations were determined with the aid of 1:120,000 Ektachrome Infrared photography obtained by the NASA aircraft program. The aerial photographic images provided the means for locating samples within homogeneous-appearing areas. At each location, data was collected pertaining to the physical terrain features and the plant species. Additional environmental data, specifically elevation, solar radiation and drainage density, were determined for each site utilizing topographic maps and NASA high altitude aircraft photography. Drainage density is the ratio of the total length of streams to the area of the sampled site. A comparison of drainage density determinations made from the high altitude aircraft photography and topographic maps indicates that the ratio is more easily and reliably obtained from the aircraft data. Solar radiation values were extrapolated from slope angle and aspect.

Computer programs employing stepwise discriminant analysis (Sampson, 1968) were used in data processing. This analysis aids in determining the importance of different variables in distinguishing groups. In this application, terrain features are "variables" and vegetation types are "groups." The variables are detailed in Figure 1. Prior to completion of the vegetation classification presented in the preceding section, this computer assisted analysis was used to determine relationships among plant species and associated terrain features. The results of that analysis were presented by Mouat (1972). Results from the vegetation type-terrain feature analysis are presented here.

The terrain features which appear to be the better discriminants of vegetation are elevation, macrorelief class, solar radiation class, drainage density, and parent material, in that order. No one feature can be used to successfully discriminate all vegetation types. Table 1 includes the means and the 95% confidence interval for elevation data for 25 vegetation types used in the analysis. Only 25 of the 31 vegetation types were included in the analysis because of an insufficient number of samples collected for six of the vegetation types. Elevation proved to be the best discriminant of vegetation types. This table shows that the range for each vegetation type, as defined by the 95%

Figure 1. Terrain feature variables.

Elevation Classes

< 3000'
3000'-3500'
3500'-4000'
4000'-4500'
4500'-5000'
> 5000'

Slope Angle

1 - < 1 1/2%
2 - 1 1/2 to 3%
3 - 3 1/2 to 10%
4 - 11 to 25%
5 - 26 to 50%
6 - > 50%

Aspect

1 - southwest
2 - south
3 - west
4 - southeast
5 - level
6 - northwest
7 - east
8 - north
9 - northeast

Solar Radiation Index

< 51 - low
51-54 - medium
> 54 - high

Parent Materials

1 - alluvium
2 - sedimentary not incl. limestone
3 - limestone
4 - intrusive igneous
5 - volcanics

Drainage Density

< 5.0 - low
5.0-7.2 - medium
> 7.2 - high

based upon length of streams in miles in plots averaging 3.14 miles^2

Figure 1. Terrain feature variables (continued).

Macrorelief

1.0 - Flat lands (regional slope < 10%)
  1.1 - nondissected
  1.2 - dissected (local relief < 10')
2.0 - Rolling (slopes 10-25%) and moderately dissected lands
  2.1 - rolling (regional slope not apparent)
  2.2 - dissected (local relief 10' to 100', regional slope apparent)
3.0 - Hilly lands (local relief > 100', slopes > 25%)
4.0 - Mountainous lands (local relief > 1000', slopes > 25%)

Landform Type

00 - landforms developed upon non-consolidated materials
01 - swale
02 - floodplain
03 - narrow floodplain
04 - alluvial terrace
05 - valley fill
06 - dissected valley fill
07 - lacustrine plain
08 - sand dunes
10 - undifferentiated bajada - non-dissected
11 - upper bajada
12 - lower bajada
13 - undifferentiated dissected bajada
14 - convex slope of dissected bajada
15 - midslope of dissected bajada
16 - interfluve
20 - landforms developed upon consolidated materials
21 - convex hillslopes
22 - upper middle hillslope
23 - middle hillslope
24 - lower middle hillslope
25 - concave hillslope
26 - interfluve
27 - drainageway
28 - pediment

TABLE I. Elevation means and 95% confidence intervals of elevation data for 25 vegetation types used in the step-wise discriminant analysis. Vegetation types are identified by number only. The numbers bear no relation to the order in which vegetation types are presented in the preceding section.

Vegetation Type	Mean Elevation (feet)	95% Confidence Interval (feet)
2	2913	2614-3212
3	3360	3082-3638
9	3587	3322-3851
6	3663	3336-3990
22 (Himu)	3978	3621-4334
21	4071	3754-4388
8	4081	3664-4498
10	4243	4109-4377
15 (Prju)	4284	4051-4517
31	4340	4076-4604
14	4435	3629-5241
29	4471	3818-5124
11	4531	4257-4805
7	4535	4397-4673
12	4546	4242-4850
27	4773	4436-5110
16	4785	4449-5121
19	4811	4545-5077
18	4879	4287-5471
25	4961	4566-5357
17	5077	4537-5616
24	5126	4834-5418
26	5244	5090-5398
30	5321	4963-5679
23 (Cebr)	5406	5230-5582

confidence interval, overlaps those of other vegetation types. These tendencies to overlap reflect a degree of ecological similarity among groups. However, when several terrain features are considered, vegetation types that showed similarity in one case may show dissimilarity in others.

Figure 2 depicts such a consideration. The three vegetation types are referred to as: (Himu), *Hilaria mutica* and *Prosopis juliflora*; (Prju), *Prosopis juliflora* and *Bouteloua* without *Nolina microcarpa*, *Quercus* and *Juniperus*; and (Cebr), *Cercocarpus brevifolius* with *Juniperus deppeana* and/or *Pinus cembroides* and usually with *Quercus*. In this case, the terrain feature, macrorelief, is sufficient for discriminating the three types. The three types are also discriminated by considering the terrain features: elevation and drainage density. This example oversimplifies the real world; however, the possibility is suggested for an ERTS image interpretation key. It would make use of the interpretability of terrain features and the ability to narrow down the likely possibilities for vegetation types on the basis of the terrain feature characteristics of a given portion of the landscape.

The following is given as an example. A location chosen from within the test site has these terrain feature values: elevation, 5320 feet; macrorelief class, 5; solar radiation class, 1; drainage density, 71 miles/square mile; and parent material, 2 (sandstone). By stepwise discriminant analysis, the following vegetation types are likely to occur where each of the above terrain features prevail.

Elevation, 5320': vegetation types 17, 18, 23, 24, 25, 26, and 30

Macrorelief class, 5: vegetation types 12, 17, 23, 25, 27, and 30

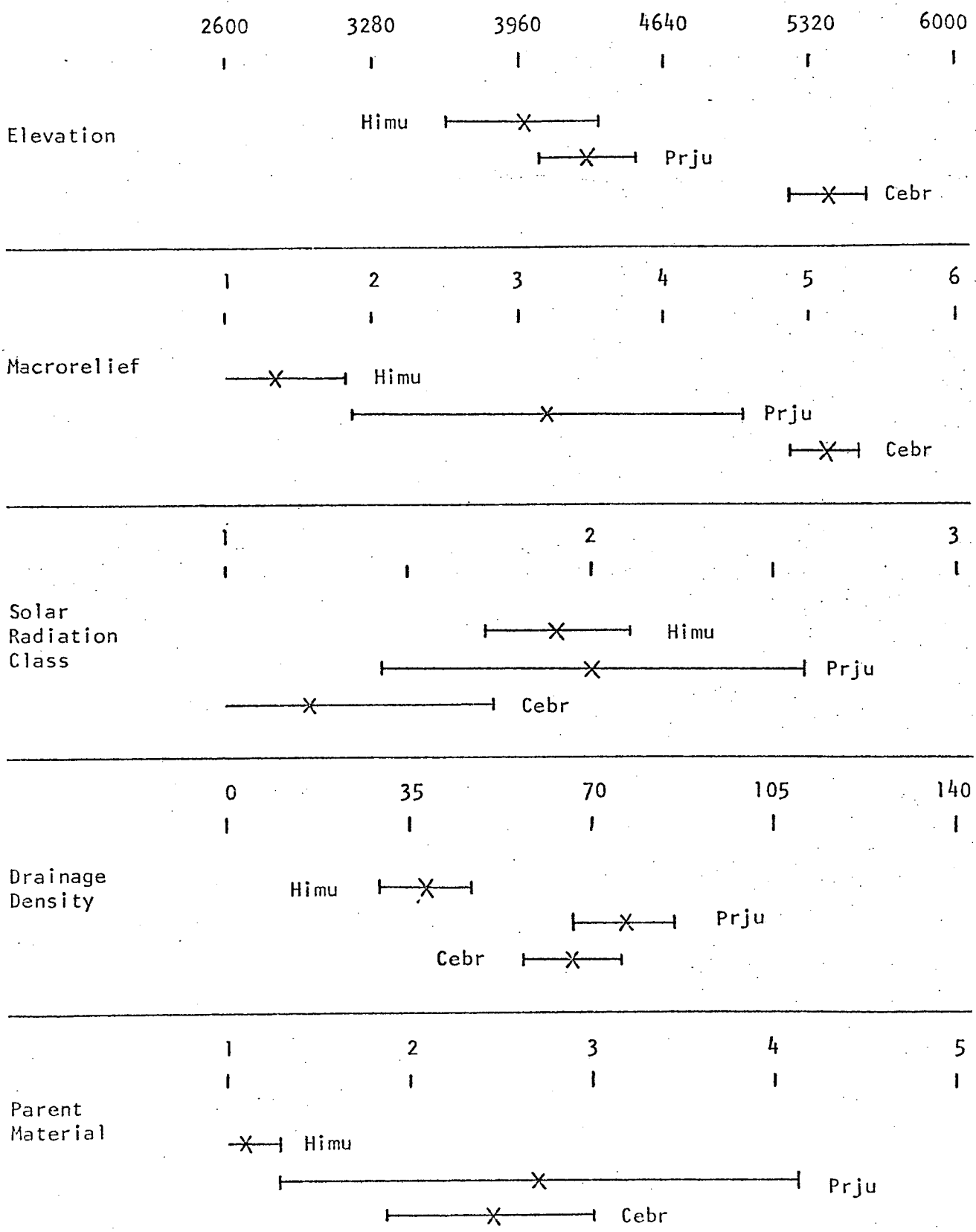
Solar radiation class, 1: vegetation types 14, 16, 17, 23, 24, 26, 27, and 30

Drainage density, 71: vegetation types 9, 10, 11, 12, 15, 16, 17, 18, 19, 23, 25, 26, 27, 29, and 31

Parent material, 2: vegetation types 3, 8, 9, 15, 16, 17, 19, 23, 25, 26, 27, 29, 30, and 31

From the above vegetation type possibilities, it is easy to determine by a process of elimination that vegetation types 17 and 23 are the types most likely to occur at this site because they are the only types included as likely possibilities in the case of the five terrain features considered. Type 23 actually occurs on the site.

Figure 2. SELECTED VEGETATION TYPE-TERRAIN FEATURE RELATIONSHIPS
(With 95% confidence interval; x = group mean)



HIGH SUN ANGLE STEREOSCOPIC VS LOW SUN ANGLE MONOSCOPIC INTERPRETATION OF MACRORELIEF ON ERTS-1 IMAGERY

A principal goal of our project has been to assess the accuracy of the interpretation of environmental features on space and high altitude aircraft imagery. While we are primarily concerned with identifying and inventorying vegetational resource features on the imagery, we recognize the difficulty of direct interpretation of those features. To surmount this problem we have turned to associated features which are more readily interpreted on space and high altitude aircraft imagery. In so doing, we have tried to establish relationships between associated environmental variables (terrain features) and vegetation. Partial results of that investigation are reported elsewhere in this report and formed the basis of a paper presented at the International Conference on the Remote Sensing of Arid Lands (Mouat, 1972).

One of the principal terrain feature variables studied has been macrorelief. Macrorelief is a gross measure of local elevational differences and slope angle. Appendix D describes the macrorelief classes. Macrorelief is considered to be one of the more salient features on space photography (Poulton, Johnson, and Mouat, 1970; Mouat, 1972). Consequently, it has been the subject of numerous interpretation tests (Poulton, Johnson, and Mouat, 1970). The interpretability of macrorelief on ERTS imagery forms the basis of this section.

An assumption is made that there is an angle of illumination which affords the greatest contrast among different relief types in arid areas. This angle of illumination might produce shadows on the steepest slopes and grazing light (relatively dark tones) on moderate slopes of the study area. Higher angles of illumination would lessen the contrast while lower angles would obscure the terrain with excessive shadowing. It was assumed, therefore, for the slope angles of the study area that an angle of illumination of 30° might prove to be ideal. Another assumption is made on the method of viewing this imagery. That is, stereoscopic interpretation of relief affords more accurate identification and delineation of subject types than monoscopic interpretation. Accordingly, it was decided that a test would be devised the purpose of which was to compare low sun angle monoscopic interpretation and high sun angle stereoscopic interpretation of ERTS imagery. This would determine if the relief accentuation afforded by low sun angle overcomes the disadvantage of not having stereo viewing.

Accordingly, an interpretation test was set up for an area for which ground truth was not known by the interpreter. The area chosen is situated in southern Maricopa County, Arizona, east of Gila Bend and containing Rainbow Valley. ERTS imagery used for the high sun angle stereoscopic interpretation test was the Mesa frame of August 23, 1972 (NASA ERTS 1031-17325) and the Gila Bend frame of August 24, 1972 (NASA ERTS 1032-17382). The elevation angle of the sun over the test area on those dates of imagery was 56°. The ERTS imagery used for the low sun angle monoscopic interpretation test was the Mesa frame of November 21, 1972 (NASA ERTS 1121-17333) on which date the elevation

angle of the sun was 31°. A 25° difference in sun elevation angle was noted between the two dates of imagery. Those ERTS frames were chosen on account of their availability, clear coverage, selection of relief forms, and relative lack of knowledge of the ground truth by the interpreter. MSS Band 5 was used for the tests. Interpretation materials were prepared at an approximate scale of 1:500,000. A study area was chosen consisting of most of the overlap area between the Mesa and Gila Bend frames. This study area covered an area having dimensions of approximately 35 by 50 miles (56 by 80 km).

The low sun angle imagery of November 21 was interpreted first, monoscopically. An attempt was made to map the macrorelief solely on the basis of the appearance of the terrain as it was imaged on the print. The test area was mapped as accurately as practicable. The high sun angle imagery of August 23 and 24 was interpreted, stereoscopically, one month later. The reasoning behind the time delay was to allow the interpreter time to forget the identification of the delineations. After the stereoscopic interpretations, a "ground truth" map was compiled from 1:62,500 USGS topographic maps. Results of each of the interpretation tests were compared to the ground truth map using a geometric dot grid as a sampling scheme. Ninety samples were used.

Results of the interpretation test comparisons are shown on Table 2. The percent accurate interpretations are shown along the bottom and right hand edges. Numbers of Type I and Type II are given in the next row up or next column over. Type I errors are considered to be errors of omission. They are errors caused when a given sample point should have been classified one way but was not. Type II errors are considered to be errors of commission resulting from classifying a sample point one way when it should not have been.

It can quickly be noted that high sun angle stereoscopic interpretation of ERTS imagery is more accurate in identifying macrorelief than low sun angle monoscopic interpretation - 71% and 50% accuracy, respectively. It must be remembered, though, that "accuracy" in these cases refers to the ground truth map as delineated and identified from topographic maps.

The table indicates the relative accuracy of identifying individual macrorelief types. The ground truth macrorelief classes 1.1, 1.2, and 2.2 were poorly interpreted on the low sun angle imagery (less than 1/3 of the identifications were correct). The ground truth classes 1.2 and 2.2 were poorly identified on the high sun angle interpretation test (also less than 1/3 accurate identifications). Images that were identified as 1.1, 3, and 4 on the low sun angle imagery were accurately identified (78%, 100%, and 100%, respectively). Concomitantly, the same interpretations on the high sun angle interpretations were accurately made (77%, 96%, and 100%, respectively). The high sun angle interpretation identified more images in class 1.1 than did the low sun angle interpretation. Both modes of interpretation were, therefore, highly successful in accurately identifying hilly and mountainous terrain. This accuracy might be a reflection of the sharp transition between hilly or mountainous terrain and flat planar surfaces. That feature of terrain diversification is characteristic of most arid regions.

Table 2. Macrorelief interpretation with high sun angle stereoscopic and low sun angle monoscopic viewing.

High Sun Angle Stereoscopic Interpretation Results

Interpretations from ERTS-1 Imagery	Identifications from Topographic Maps						Total Interpreted	# Type II Errors	% Correct
	1.1	1.2	2.1	2.2	3	4			
1.1	33	8	0	2	0	0	43	10	77
1.2	12	4	0	2	0	0	18	14	22
2.1	0	0	0	0	1	0	1	1	0
2.2	0	1	0	1	0	0	2	1	50
3	0	0	0	0	23	0	23	0	100
4	0	0	0	0	0	3	3	0	100
Total in Sample	45	13	0	5	24	3	90	26	71
# Type I Errors	12	9	0	4	1	0	26		
% Correct	73	31	-	20	96	100	71		

Table 2. Macrorelief interpretation with high sun angle stereoscopic and low sun angle monoscopic viewing (Continued).

Low Sun Angle Monoscopic Interpretation Results

		Identifications from Topographic Maps						Total Interpreted	# Type II Errors	% Correct
		1.1	1.2	2.1	2.2	3	4			
Interpretations from ERTS-1 Imagery	1.1	14	4	0	0	0	0	18	4	78
	1.2	20	3	0	4	0	0	27	24	11
	2.1	0	0	0	0	0	0	0	0	+
	2.2	11	6	0	1	0	0	18	17	6
	3	0	0	0	0	24	0	24	0	100
	4	0	0	0	0	0	3	3	0	100
Total in Sample		45	13	0	5	24	3	90	45	50
# Type I Errors		31	10	0	4	0	0	45		
% Correct		31	23	-	20	100	100	50		

It appears, therefore, that from the basis of this preliminary interpretation comparison test, that low sun angle monoscopic interpretation of macrorelief is not as accurate as high sun angle stereoscopic interpretation of relatively flat topography.

PLANT PHENOLOGICAL CHANGES RECORDED BY MULTIDATE ERTS-1 DATA

The concept of utilizing multidate, remotely sensed data for identification of natural vegetation types in this arid and semi-arid region was put forth in Poulton, et al., (1969), and discussed further in Poulton, et al., (1970). General plant phenological patterns were recognized; depending upon the pattern followed, a plant species was identified as evergreen, cool season deciduous or warm season deciduous. Satellite and high altitude aircraft imagery provided evidence from which to conclude that the three phenological patterns could be exhibited by vegetation types as well as plant species. Such manifestations appeared to occur when either one plant species or a group of species with similar phenologies were distinctly most prominent in the vegetation stand and contributed sufficient ground cover to dominate the spectral return from the site. Vegetation types which were characterized by stands having low vegetative ground cover values did not have image changes on multidate photography that appeared related to phenological changes.

At that time, review of the available satellite and small scale aerial photography provided the basis for formulating ideas pertaining to vegetation inventory procedures, specifically utilizing sequential views of the objects under study. It did not prove possible, however, to gather the sequential data necessary for refining the procedure and determining some limitations in its application.

The ERTS-1 satellite with supporting NASA aircraft programs now are providing the necessary data. Several dates of imagery have been received which document the advent of dormancy of both cool season and warm season deciduous plant species and their respective vegetation types. The phenological change cited has been made most obvious in a qualitative manner by preparing reconstituted color composites for six available dates of imagery from August 22, 1972 (NASA ERTS E-1030-17271) to December 26, 1972 (NASA ERTS E-1156-17280). The color reconstitutions were prepared by the diazo process. The vegetation types that underwent the more distinctive changes were herbaceous (grassland) types, and riparian (grassland, shrub, and woods) types. Additionally, the development of winter annuals has been documented by ERTS-1. This development is readily identified on the color composites of the satellite imagery. The characteristic red coloration of green vegetation is present in color composites at a time of year (December 26) and degree of saturation that could only be the result of the presence of annual vegetation. The region containing the study area received an unusually lengthy summer rainy season. This resulted in changes in phenological timings that appear atypical. The small scale aerial photography obtained by the aircraft program at the NASA Ames facility is providing the necessary supporting information required in accounting for the unanticipated phenological patterns within the large area being sampled.

The comments offered here are not presented as results of ERTS-1 data analysis. Those results will follow now that a vegetation classification for the region has been completed. The observations do serve notice of the very real application that the ERTS data can have in natural vegetation inventory.

PROGRAM FOR NEXT REPORTING INTERVAL

Data analysis will continue for characterizing relationships among vegetation types and associated terrain features. Considerations needing specific attention are relationship of soil color and vegetation type, and the manner in which to best portray the range of values for each terrain feature as exhibited by each vegetation type. This latter consideration is necessary in light of the application to be made of these types of relationships in ERTS imagery interpretation as noted at the end of the section entitled "Vegetation-Terrain Feature Relationships."

Work already initiated for the evaluation of interpretative detail inherent in ERTS-1 imagery, and in the development of multistage sampling procedures for determining kinds and amounts of natural vegetation will be continued. Experiments, involving grouping ERTS-1 images into categories having similar characteristics, are being utilized to evaluate interpretability for progressively finer levels of subject detail.

Analysis of multidate ERTS-1 data for plant phenological changes will be initiated. This work will begin with densitometric measurements of ERTS-1 images of known subjects. Values thus obtained will be compared within date only to establish a ranking of apparent spectral reflectivity by vegetation subjects. Rankings will be compared among dates.

Preparations will be made for analysis of ERTS-1 digital data on computer compatible tapes. Dates of data have been selected for analysis and tapes ordered retrospectively. That order has been partially received.

The investigation reported herein has already made use of the vegetation classification also contained in this report. That classification will also be extensively used in the investigations planned. At this time, it appears that some of the results of the vegetation-terrain feature relationship study will also be used in the multistage sampling experiment and the analysis of multidate ERTS data for plant phenological changes.

CONCLUSIONS

There are vegetation types present within the study area that are repeated at various locations; the stands of vegetation at those various locations can be recognized as representatives of specific vegetation types. There are at least 31 types occurring in the study area.

The vegetation types exhibit relationships with terrain features. For this reason, those terrain features, for which stronger relationships are evident, can be used to discriminate vegetation types. ERTS-1 images can be characterized in terms of their terrain feature characteristics and then in terms of the vegetation types which are more likely to be associated with that specific mix of characteristics. Elevation, macrorelief, drainage density, and soil parent material are the better discriminants of vegetation types.

Stereoscopic viewing of ERTS-1 images provides a definite advantage over monoscopic viewing for identifying those macrorelief classes found in areas of relatively flat terrain in an arid environment. Low sun angle did not improve image interpretability sufficiently to overcome the lack of stereoscopic viewing. Hilly and mountainous terrain were identified with equal facility with or without stereoscopic viewing.

A cursory, qualitative inspection of color reconstitutions of ERTS-1 images indicates that the plant species of some vegetation types are undergoing phenological changes which are being recorded by the MSS system.

RECOMMENDATIONS

The impact that sun angle can have on the facility with which terrain features can be interpreted should be investigated further. The single test conducted thus far left unanswered the question of optimum sun angles for the different classes of macrorelief. The same may also be asked for other terrain features, especially those which are proving most useful for discriminating vegetation types.

APPENDIX A

Prominence ratings: concept and definitions (from Poulton, Faulkner, and Martin, 1971).

Prominence Rating: Past usage of the common five-unit scale of "Abundance" involved vague meanings of "very abundant," "common," "rare," etc. We have more precisely defined five "prominence classes" to facilitate rapid but meaningful recording of the visual appearance, aspect or physiognomy of the plant community. The usefulness of the system has been tested and proved satisfactory in many kinds of vegetation. It is a particularly useful technique for the field man who is in a hurry, yet data taken by different people is sufficiently consistent for accurate ecological classification. These ratings are to be based on the entire community taken as a unit, not on the separate layers.

Prominence Rating	Description of Class or Meaning of Symbol
5	The most prominent species in the stand; the most obvious species in terms of amount present. Impression on the observer is that there is clearly more of the subject species than any other. Some stands may not have a species that clearly rates "5" and the class would be omitted. A stand can have only one species with this prominence level.
4	Clearly the second most prominent species in the stand or one of a group of species that share about equally in being most prominent (in which case each is accorded a prominence of "4"). All remaining species are definitely less prominent than the subject species. May have more than two species in this class, but usually only one or two. If the subject species seem more prominent than all others in the stand but observer has difficulty deciding which one would rate a "5", the guideline is to assign each member of the group a prominence of "4" without using class "5".
3	A rather uniformly distributed species that is easily seen by standing at one place in the stand and looking casually around. Do not have to look intently to see the species. Species may fall into this class if they are initially hard to see because of small stature but once located are easy to see. Usually there are numerous species accorded a prominence of "3". Definitely not in prominence "4" or "5"; the species blends among the mass of species in the stand.

APPENDIX A
(Continued)

Prominence ratings: concept and definitions (from Poulton, Faulkner, and Martin, 1971).

Prominence Rating	Description of Class or Meaning of Symbol
2	A species that can be seen only by looking intently while standing in one place or by moving around in the stand. Species occurring in patches encountered by moving about would be rated in prominence class "2" even though, within a patch, they may rate a higher prominence score. Not so rare that one must look in and around other plants to see the species.
1	Species that can be seen only by searching for them in and around other plants. Considerable care is required to find species rating prominence class "1". Species which occur in extremely wide-scattered small patches or clumps of individuals would rate a prominence "1" provided they do not represent an "inclusion" of a different plant community.

APPENDIX B

Technical legend on physiognomic and structural characteristics of vegetation (excerpts from Poulton, 1972, with modifications).

NATURAL VEGETATION Subclasses

Herbaceous types

- prominently annuals
- bunchgrass steppe
- sodgrass and mixed sodgrass-bunchgrass steppe and prairie
- undifferentiated complexes of herbaceous types

Shrub-scrub types

- microphyllous, non-thorny scrub, generally with succulents
- microphyllous thorn scrub
- succulent scrub
- microphyllous saltsage and related scrub types
- shrub steppe (single species or simple mixtures of shrubs)
- evergreen sclerophyll shrub
- deciduous macrophyllous shrub

Intergrade types

- scattered tall shrub
- scattered broad-leaved tree) over herbs
- scattered needle-leaved tree)
- scattered needle-leaved tree) over low shrubs
- scattered broad-leaved tree)

Forest and woods types

- needleleaf
- broadleaf
- mixed forests of needleleaf-broadleaf

APPENDIX C

Plant Species List

Growth Form	Scientific Name	Common Name
Trees	Chilopsis linearis	desert willow
	Fraxinus velutina	ash
	Juniperus spp.	juniper
	J. deppeana	alligator juniper
	J. monosperma	one-see juniper
	Pinus spp.	pine
	P. cembroides	Mexican pinyon
	P. engelmannii	Apache pine, Arizona long leaf pine
	P. leiophylla var chihuahuana	Chihuahua pine
	P. ponderosa	Ponderosa pine
	P. strobiformis	Mexican white pine
	Platanus wrightii	Arizona sycamore
	Populus fremontii	Fremont cottonwood
	P. tremuloides	quaking aspen
	Pseudotsuga menziesii	Douglas fir
	Quercus spp.	oak
	Q. arizonica	Arizona white oak
	Q. emoryi	Emoryi oak
	Q. gambelii	Gambel oak
	Q. hypoleucoides	silverleaf oak
	Q. oblongifolia	Mexican blue oak
	Q. reticulata	net-leaf oak
	Robinia neomexicana	New-Mexican locust
Shrubs and half shrubs	Acacia constricta	white-thorn acacia
	A. greggii	catclaw acacia
	A. vernicosa	mescat acacia
	Aloysia wrightii	Wright's lippia
	Arctostaphylos pungens	point-leaf manzanita
	Atriplex canescens	four-wing saltbush
	Baccharis pteronioides	yerba-de-pasmo
	Calliandra eriophylla	fairy duster
	Ceanothus spp.	
	Celtis spp.	hackberry
	C. pallida	desert hackberry
	Cercidium floridum	blue palo-verde
	C. microphyllum	little-leaf palo-verde
	Cercocarpus breviflorus	little-leaf mountain mahogony
	Coldenia canescens	

APPENDIX C
(Continued)

Plant Species List

Growth Form	Scientific Name	Common Name
Shrubs and half shrubs	Condalia lycioides	gray-thorn
	C. spathulata	Mexican crucillo
	Cowania mexicana	quinine-bush
	Dalea formosa	feather dalea
	Encelia farinosa	brittlebush
	Ephedra trifurca	Mexican tea
	Flourensia cernua	tarbush
	Fouquieria splendens	ocotillo
	Franseria deltoidea	triangle bursage
	Garrya wrightii	silktassel
	Haplopappus tenuisectus	burro goldenweed
	Koeberlinia spinosa	crucifixion thorn
	Krameria parvifolia	range ratany
	Larrea tridentata	creosote bush
	Lycium spp.	desert-thorn
	Mimosa spp.	
	M. biuncifera	wait-a-minute
	M. dysocarpa	velvet-pod mimosa
	Mortonia scabrella	mortonia
	Parthenium incanum	mariola
	Prosopis juliflora	mesquite
	Psilostrophe cooperi	paper flower
	Rhus choriophylla	
	R. microphylla	sumac
	R. trilobata	squaw bush
	Zinnia pumila	desert zinnia
Leaf succulents	Agave spp.	century plant
	A. palmeri	century plant
	A. parryi	century plant
	A. schottii	amole
	Dasylirion wheeleri	sotol
	Nolina microcarpa	beargrass
	Yucca spp.	yucca
	Y. baccata	banana yucca
	Y. elata	soaptree yucca
	Y. schottii	Schott's yucca

APPENDIX C
(Continued)

Plant Species List

Growth Form	Scientific Name	Common Name
Stem succulents	Cereus giganteus	saguaro
	Ferocactus wislizenii	barrel cactus, bisnaga
	Opuntia spp.	cholla, prickly pear
	O. fulgida	jumping cholla
	O. phaeacantha	prickly pear
	O. spinosior	cane cholla
Grasses	Andropogon spp.	bluestem
	A. barbinodis	cane beardgrass
	Aristida spp.	three-awn
	Bouteloua spp.	grama
	B. chondrosioides	sprucetop grama
	B. curtipendula	side-oats grama
	B. eriopoda	black grama
	B. gracilis	blue grama
	B. hirsuta	hairy grama
	B. rothrockii	rothrock grama
	Eragrostis spp.	love grass
	Hilaria belangeri	curly mesquite
	H. mutica	tobosa grass
	Muhlenbergia spp.	muhly
	M. porteri	bush muhly
	Panicum spp.	
	Setaria spp.	bristle grass
	Sporobolus spp.	dropseed
	S. wrightii	Wright sacaton
	Tridens pulchellus	fluffgrass

APPENDIX D

MACRORELIEF CLASSES adapted to fit the geomorphology of southern Arizona (modified from Poulton, Johnson, and Mouat, 1970).

Classes	Description
1	A generally flat landscape with prominent slopes less than 10%.
1.1	The landscape is essentially smooth. Dissection is minimal. The regional slope in this class is nearly always between 0 and 3%.
1.2	The landscape is relatively flat; however, dissection has progressed to a noticeable point. Dissection is either sharp and widely spaced (in which case side slopes may be over 10%), or gently rolling (less than 10% side slopes) and more closely spaced. Where side slopes exceed 10%, relief is generally less than 10 feet.
2	A rolling or moderately dissected landscape with prominent slopes 10 to 25% (side slopes may exceed that figure in the case of dissected planar surfaces).
2.1	The landscape is rolling or hilly; a low angle regional slope is not readily apparent. Occasionally, as in tilted tablelands, a regional slope of 10 to 25% may be present. Rare in southern Arizona.
2.2	The landscape consists of a moderately to strongly dissected planar surface (i.e., pediment, bajada, valley fill, etc.). The regional slope is generally between 2 and 6%; side slopes must be steeper than 10%. If side slopes are steeper than 25%, relief must be less than 100 feet. The drainage network is usually finer textured than that of the 1b class.
3	The landscape is hilly to submountainous; slopes are moderate to steep, predominantly exceeding 25%. Relief is generally over 100 feet, but less than 1000 feet. Where relief approaches 1000 feet, the landform system appears to be relatively simple - with smooth slopes. Drainage systems generally have the same base level.

APPENDIX D
(Continued)

MACRORELIEF CLASSES adapted to fit the geomorphology of southern Arizona (modified from Poulton, Johnson, and Mouat, 1970).

Classes	Description
4	The landscape is mountainous, having high relief, usually over 1000 feet. Slopes are moderate to steep, frequently exceeding 50%. The landform and drainage systems are usually complex, with drainage systems having local base levels quite independent of one another.

REFERENCES

Darrow, R. A. Arizona range resources and their utilization. I. Cochise County. The University of Arizona Agricultural Experiment Station Technical Bulletin 103. Tucson. 1944.

Garcia-Moya, E. A preliminary vegetation classification of the Tombstone, Arizona, vicinity. PhD Thesis. Rangeland Resources Program, Animal Science Department. Oregon State University, Corvallis. 195 pp. 1972.

Humphrey, R. R. Forage production on Arizona ranges. V. Pima, Pinal and Santa Cruz Counties. The University of Arizona Agricultural Experiment Station Bulletin 302. Tucson. 1960.

Humphrey, R. R. Arizona natural vegetation. Map. The University of Arizona Agricultural Experiment Station and Cooperative Extension Service Bulletin A-45. Tucson. 1963.

Interagency Technical Committee (Range), The. Vegetative units of the major land resource areas, Arizona. The University of Arizona. Agricultural Extension Service. Agricultural Research Service. Soil Conservation Service. Portland, Oregon. 1963.

Lowe, C. H., ed. The vertebrates of Arizona. University of Arizona Press, Tucson. 1964.

Mouat, D. A. Vegetation-terrain feature relationships in southeast Arizona. IN: Proceedings, 3rd Annual ARETS Symposium, International Conference on Remote Sensing in Arid Lands, November 8, 9, and 10, 1972, University of Arizona, Tucson. 19 pp. 1972. (Available from U.S. Dept. of Commerce, National Technical Information Service, microfiche item E72-10228.)

Nichol, A. A. The natural vegetation of Arizona. The University of Arizona Agricultural Experiment Station Technical Bulletin 127. Tucson. 1952.

Pond, F. W. and J. W. Bohning. The Arizona chaparral. Arizona Cattlelog 27(10) and 27(11). 1971.

Poulton, C. E. Inventory and analysis of natural vegetation and related resources from space and high altitude photography. Final Research Report, Remote Sensing Applications in Forestry for Earth Resources Survey Program, OSSA/NASA by Rangeland Resources Program staff, Oregon State University, Corvallis. 50 pp. 1972.

Poulton, C. E., D. P. Faulkner, J. R. Johnson, D. A. Mouat, and B. J. Schrumpf. High altitude photography in the analysis of natural vegetational resources with implications in land use. IN: Pettinger, et al., The application of high altitude photography for vegetation resource inventories in southeastern Arizona. Final Report on Contract NAS9:9577 for Earth Observations Division, MSC/NASA, by Forestry Remote Sensing Laboratory, University of California, Berkeley. 147 pp. 1970.

REFERENCES
(Continued)

Poulton, C. E., D. P. Faulkner, J. R. Johnson, D. A. Mouat, and B. J. Schrumpf. Inventory and analysis of natural vegetation and related resources from space and high altitude photography. Annual Progress Report, Remote Sensing Applications in Forestry for Earth Resources Survey Program, OSSA/NASA by Range Management Staff, Oregon State University, Corvallis. 59 pp. 1971.

Poulton, C. E. D. P. Faulkner, and N. L. Martin. A procedural manual for resource analysis--Application of ecology and remote sensing in the analysis of range watersheds. Final Project Report to Bureau of Land Management, U.S.D.I. Range Management Program, Agricultural Experiment Station, Oregon State University, Corvallis. 133 pp. 1971.

Poulton, C. E., E. Garcia-Moya, J. R. Johnson, and B. J. Schrumpf. Inventory of native vegetation and related resources from space photography. Annual Progress Report, Remote Sensing Applications in Forestry for Earth Resources Survey Program, OSSA/NASA by Range Management Staff, Oregon State University, Corvallis. 66 pp. 1969.

Poulton, C. E., J. R. Johnson, and D. A. Mouat. Inventory of native vegetation and related resources from space photography. Annual progress Report, Remote Sensing Applications in Forestry for Earth Resources Survey Program, OSSA/NASA by Range Management Staff, Oregon State University, Corvallis. 32 pp. 1970.

Sampson, P. BMD07M. Stepwise discriminant analysis. IN: BMD Biomedical Computer Programs, ed., W. J. Dixon. University of California Publications in Automatic Computations No. 2, Los Angeles. 1968.

Shreve, F. The vegetation of Arizona. U.S. Department of Agriculture, Miscellaneous Publication 423:10-23. 1942.

Shreve, F. and I. L. Wiggins. Vegetation and flora of the Sonoran Desert. Volume One. Stanford University Press, Standford, California. 1964.